1 Introduction

In this chapter…

- *Puget Sound hydrology*
- *Current stormwater management*
- *Impacts of urbanization*
- *Low impact development goals and objectives*

1.1 Puget Sound Hydrology

Native forests of the Puget Sound lowlands intercept, store, and slowly convey precipitation through complex pathways. Water budget studies of wet coniferous forests in western Washington, British Columbia, and the United Kingdom indicate that approximately 50 percent of the annual rainfall is intercepted by foliage and evaporated during the rainy season. Bauer and Mastin (1997) found that interception and evaporation from vegetation during the winter months (approximately 50 percent) far exceeded estimates for western Washington, and attributed the high rate to the large surface area provided by evergreen trees, relatively warm winter temperatures, and the advective evaporation of precipitation. Bidlake and Payne (2001) and Calder (1990) also found that the aerodynamically rough forest canopy and **advection energy** supported evaporation rates of intercepted precipitation that were higher than estimated radiation-based potential **evapotranspiration**.

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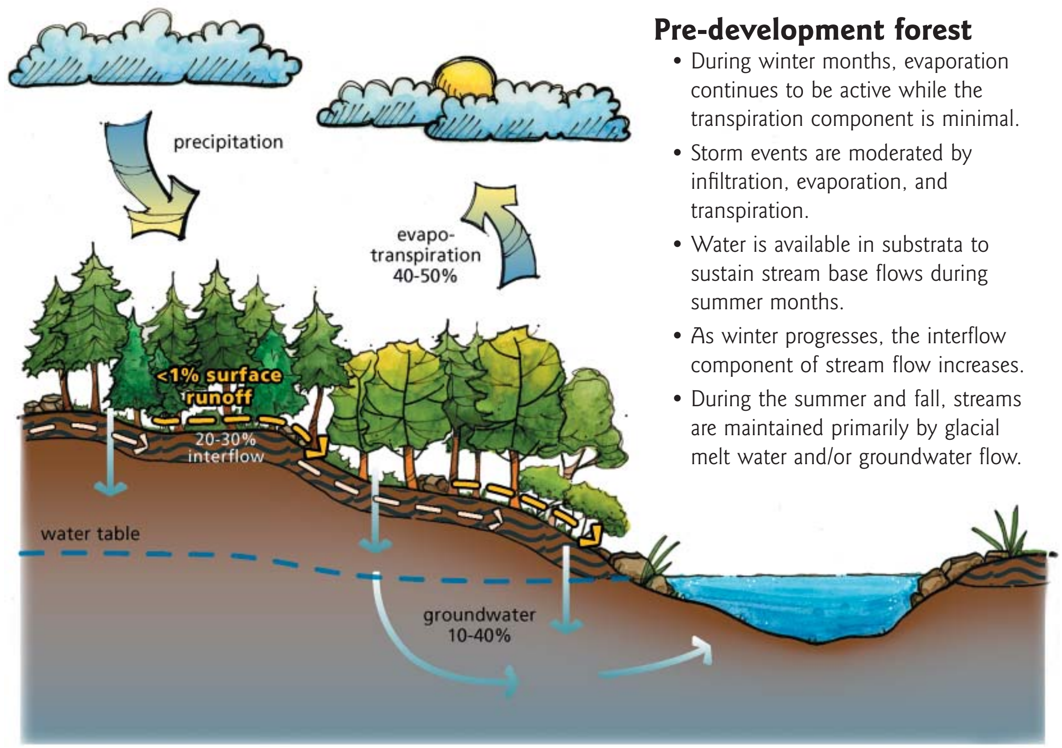
Native soils also play a critical role in storage and conveyance of Pacific Northwest (PNW) rainfall. Typically, 2 to 4 feet of soil, high in organic material and biologically active near the surface, overlays the subsurface geology. Solar radiation and air movement provide energy to evaporate surface soil moisture that contributes to the overall evapotranspiration component. Soil biota and organic matter chemically and physically bind mineral particles into stable aggregates that build soil structure, increase soil porosity, and provide 20 to 30 percent of active water storage by volume. Shallow subsurface flow (interflow) moves slowly down slope or down gradient over many hours, days or weeks through these upper soil layers. Depending on the underlying soil type and structure, 10 to 40 percent of the annual precipitation moves to deeper groundwater (Bauer and Mastin, 1997).

For most storm events, the gentle rainfall intensities are less than the combined capacity of the interception loss, and vegetation and soil storage in native Puget Sound forests; as a result, overland flow does not occur or is minimal (Booth, Hartley and Jackson, 2002). Instead, the storm flow moves downslope below the surface at a much slower rate than overland flow and displaces antecedent, subsurface water in areas near streams, lakes and wetlands (Bauer and Mastin, 1997). The displaced soil water adjacent to water bodies contributes to stream flows or wetland and lake levels rather than the entire watershed. As storms and the wet season progress, available soil storage capacity declines and the saturated or contributing areas near receiving waters increase as does the response to storm events (Booth et al., 2002).

Figure 1.1 Water budget for pre-development Puget Sound lowland forests.

Graphic by AHBL Engineering



Pre-development forest

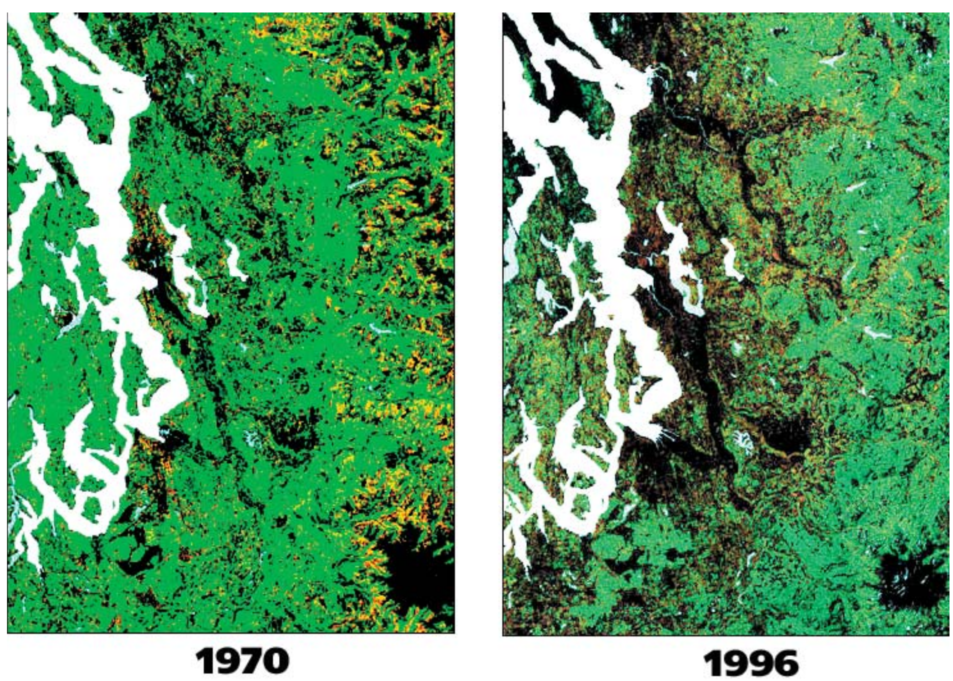
- During winter months, evaporation continues to be active while the transpiration component is minimal.
- Storm events are moderated by infiltration, evaporation, and transpiration.
- Water is available in substrata to sustain stream base flows during summer months.
- As winter progresses, the interflow component of stream flow increases.
- During the summer and fall, streams are maintained primarily by glacial melt water and/or groundwater flow.

1.2 Impacts of Urbanization

The transition from a native landscape to a built environment increases the impervious surface coverage of roads, parking areas, sidewalks, rooftops, and landscaping. These changes reduce, disrupt or entirely eliminate native vegetation, upper soil layers, shallow depressions, and native drainage patterns that intercept, evaporate, store, slowly convey, and infiltrate stormwater. As development progresses, the area in small watersheds that contribute overland flow to receiving waters in minutes increases while the area that stores and delivers subsurface flow over periods of hours, days or weeks diminishes (Booth et al., 2002).

Figure 1.2 Satellite images of Puget Sound in 1970 and 1996. (Dark color in lowlands areas indicates clearing of vegetation and development.)

Source: American Forests



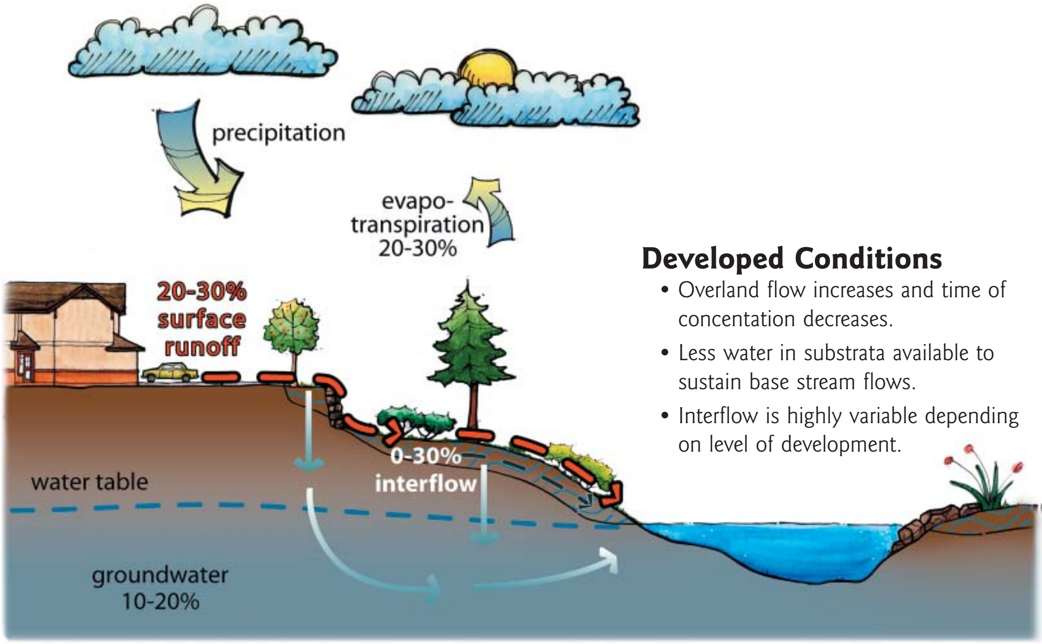


Figure 1.3 Water budget for typical suburban development in the Puget Sound lowlands.

Graphic by AHBL Engineering

Loss of native soils and vegetation within the watershed and associated changes in hydrologic regimes can significantly degrade stream habitat (Booth, 1991). **Bankful discharges**—the 1- to 1.5-year return storm flow that does much of the work to form a stream channel—increase in magnitude and frequency (Center for Watershed Protection [CWP], 2000a). Typical responses in streams exposed to high flows for longer periods of time include: excessive streambed and stream bank instability (May, Horner, Karr, Mar, and Welch, 1997); increased stream channel cross-sectional area (typically, cross sectional area is enlarged 2 to 5 times depending on the amount of total impervious area and other development factors (CWP, 2000a and March 2000); and overall loss of habitat structure, and hydraulic diversity (Booth, 1991). While water quality conditions (as defined by dissolved oxygen, temperature, sediment, various pollutant concentrations, and other parameters) are critical considerations for managing stream health, altered watershed hydrologic regimes and associated channel instability are a leading cause for in-stream physical habitat degradation and initial loss of **biotic integrity** (May et al., 1997).

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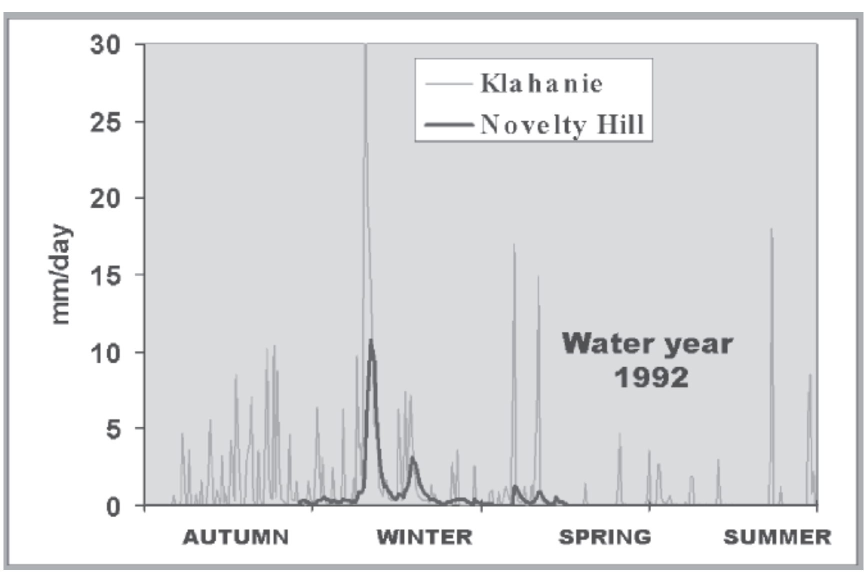

Figure 1.4 Hydrograph for an urban (Klahanie) and a rural watershed (Novelty Hill) in the Puget Sound lowlands. Storm flows increase in magnitude and frequency in the urban watershed.

Source: 'Hydrological Effects of Land-use Change in a Zero-order Catchment.'

Burges, Wigmosta and Meema, 1998. Journal of Hydrologic Engineering. *Material reproduced with permission from the American Society of Civil Engineers.*

Figure 1.5 Down-cut stream channel resulting from increased storm flow generated by nearby development (Gig Harbor Peninsula).

Photo courtesy of Hans Hunger

Streams respond to watershed urbanization through several other important mechanisms as outlined in Table 1.1 (MacCoy and Black, 1998; May et al., 1997; Staubitz, Bortleson, Semans, Tesoriero, and Black 1997; and Washington Department of Ecology [Ecology], 1999).

Table 1.1 Degradation of watershed conditions and stream response.

Change in watershed condition	Response
Increased drainage density due to road networks, road crossings and stormwater outfalls	Increased storm flow volume and frequency, and channel erosion Increased fine sediment and urban water pollutant loads Increased fish passage barriers
Increased fine sediment deposition	Reduced intergravel dissolved oxygen levels in streambed Loss of salmonid spawning and macroinvertebrate habitat
Loss or fragmentation of riparian areas	Reduced delivery of large woody debris Reduced bank stability and loss of bank habitat structure and complexity Reduced shading and temperature control
Reduced quantity and quality of large woody debris	Reduced channel stability, sediment storage, instream cover for fish and insects, loss of pool quality and quantity
Increased pollutant loads	Synthetic organic compounds and trace elements: some acutely toxic; tumors in fish; salmon and trout will alter spawning and migration behavior in presence of metals as low as <1% of lethal concentration; **endocrine disruptors** (18 of 45 suspected endocrine disrupting trace elements found in Puget Sound fish tissue) Nutrients: excessive aquatic plant growth; excessive **diurnal oxygen fluctuations** Synergistic influence of multiple pollutants unknown

The cumulative impact of hydrologic alteration and the various other changes in watershed conditions can result in channel instability and degraded biotic integrity at low or typically rural levels of watershed development. Studies conducting empirical stream assessments observed physical degradation of channels with **effective impervious area** (EIA) percentages of less than 10 percent within the contributing watersheds (Booth et al., 2002). While impervious surface coverage generally is low at this density, forest clearing for pasture, lawns and hobby farms can be extensive across the rural landscape. Hydrologic analysis of the same watersheds (see Figure 1.6) observed the same relationship between low levels of imperviousness, changes in modeled stream flows (recurrence of pre-developed forest and developed flows), and stream channel stability. Booth, Hartley and Jackson (2002) note that observed channel instability is a relatively insensitive evaluation tool and the lack of observed degradation does not guarantee the absence of subtle, but important consequences for the physical or biologic health of streams.

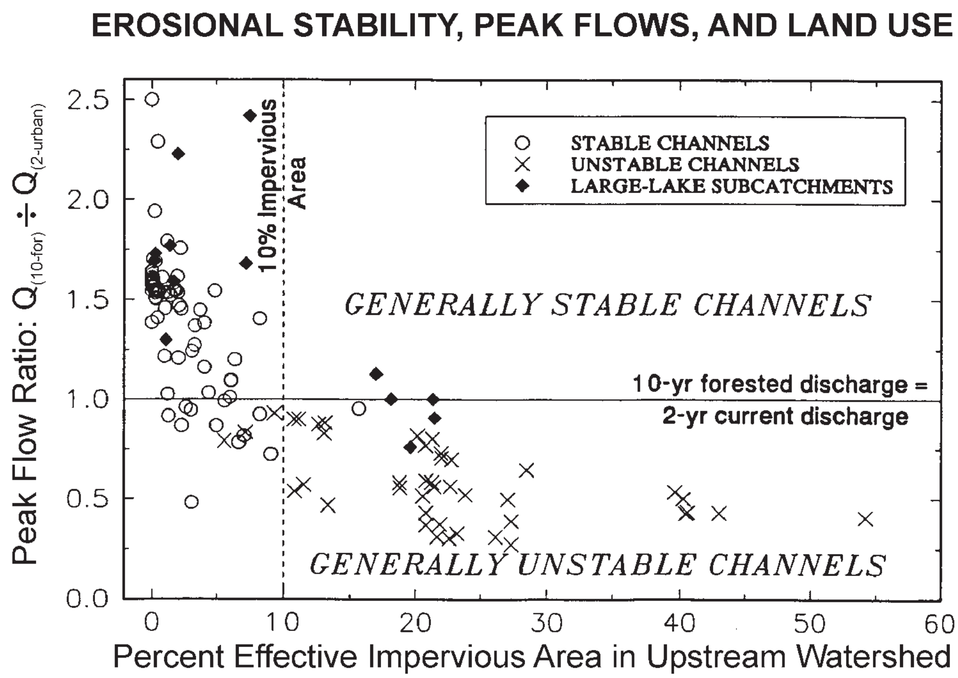

Figure 1.6 Observed stable and unstable stream channels in the Puget Sound lowlands plotted by percent EIA and ratio of modeled 10-year forested and 2-year urbanized discharges. Stable channels in this study consistently meet the apparent thresholds of EIA <10% and $Q_{(2\text{-urban})} \leq Q_{(10\text{-forest})}$ (Booth et al., 2002).

Graph courtesy of Booth and Jackson, 1997

The physical and chemical composition of wetlands and lakes are altered in response to land development as well. Typically, water levels in wetlands gradually rise in the beginning of the wet season and then subside slowly as the wet season ends. Wetland plant species have adapted to this fairly narrow and stable range of water depths and soil saturation (CWP, January 2000c). As development proceeds and impervious surfaces replace native vegetation and soils, water levels can rise rapidly in response to individual storms. A major finding in the Puget Sound Wetlands and Stormwater Management Program was that "hydrologic changes were having more immediate and measurable effects on composition of vegetation and amphibian communities than other conditions [monitored]" (Azous and Horner, 2001). Decline in wetland plant and amphibian species richness are likely when:

- Mean annual water level fluctuations exceed 20 centimeters per year.
- The frequency of **stage excursions** of 15 cm above or below pre-development condition exceeds an annual average of six.
- The duration of stage excursions of 15 cm above or below pre-development condition exceeds 72 hours per excursion.

- The total dry period (when pools dry down to the soil surface everywhere in the wetland) increases or decreases by more than two weeks in any year (Azous and Horner, 2001).
- Increased water level fluctuations occur early in the growing season (CWP, January 2000c).

Increased water level fluctuations of this nature are observed when total impervious area within the drainage area exceeds 10 to 15 percent (Taylor, 1993).

Lakes and estuaries, while not as prone to morphological change due to altered hydrology, are highly susceptible to shoreline modifications and water quality degradation from urbanization. Phosphorus, bacteria and sediment are typical urban stormwater pollutants impacting lakes. Phosphorus is often a limiting nutrient in fresh water systems, and contributes to increased plant growth and diurnal oxygen level fluctuations that degrade wildlife habitat, recreational opportunities and other beneficial uses.

Bacteria can restrict or close shellfish growing areas in Puget Sound to harvest. Nonpoint source pollution (including stormwater runoff) is now “the most common cause of shellfish classification downgrades in Puget Sound, reducing the region’s commercially approved acreage by approximately 25 percent since 1980” (PSAT, 2004). Toxic pollutants associated with stormwater sediments (e.g., heavy metals and polycyclic aromatic hydrocarbons) that settle in urban estuaries and near shore areas have contributed to the listing of several urban bays as Superfund (federal) or Model Toxic Control Act (state) clean-up sites.

1.3 Current Stormwater Management

Conventional tools to manage stormwater are mitigation-based and flood-control focused. This strategy emphasizes the efficient collection and rapid conveyance of runoff from residential and commercial development to central control ponds. Several factors have led to the implementation and continuation of this approach: stormwater has been perceived as a liability and applications have evolved from wastewater technology; hard conveyance structures and central control ponds are considered reliable and relatively simple to maintain; the conveyance and collection approach is relatively simple to model for regulatory requirements; and construction costs are readily estimated.

Conventional tools to manage stormwater are mitigation-based and flood-control focused.

Newer conveyance and pond strategies, if properly designed and maintained, can match modeled pre-development peak flows and runoff rates discharged from development sites; however, a number of problems will continue to challenge current management strategies. These include:

- *Peak and volume control*. Typical residential and commercial development practice in the Puget Sound removes most, if not all, vegetation and topsoil. Suburban development in the region is estimated to have 90 percent less stormwater storage than the native forested condition, and BMP applications (circa 1994) are estimated to recover approximately 25 percent of that storage (May et al., 1997). Without infiltration, excess volume generated above the onsite storage capacity is released to receiving waters. If flows exceed **critical shear stresses,** stream channels are exposed to excessive erosion over prolonged periods (Booth et al., 2002). (See Figure 1.7 for graphic representation of actual storage needed to replace loss of native soil and vegetation.)

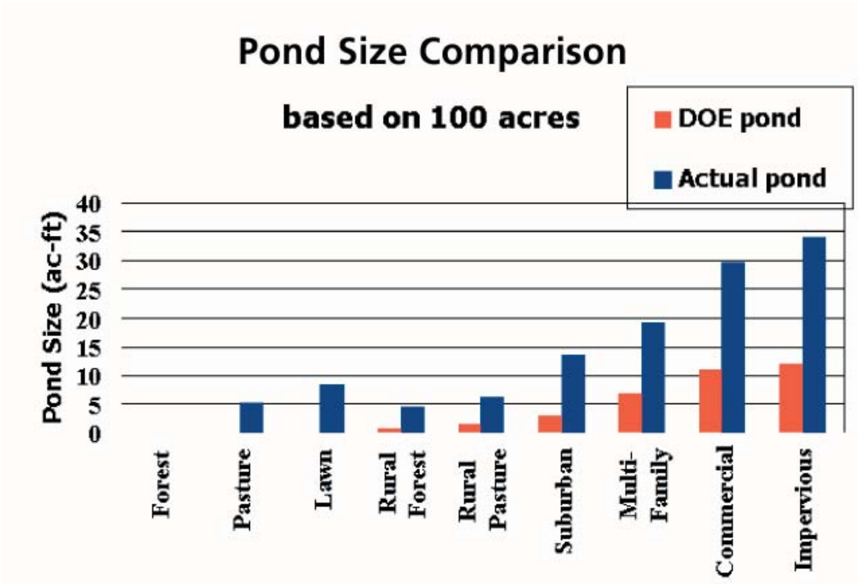

Figure 1.7 Storage required to meet Washington State Department of Ecology's stormwater management requirement (DOE Pond) and actual storage needed (actual pond) to replace loss of native soil and vegetation storage on a 100-acre site.

Source: Beyerlein, 1999.

- *Spatial Distribution*. Conventional management converts spatially distributed subsurface flows to point discharges. No analysis is currently available that focuses on the larger hydrologic impacts of this transition; however, locally severe erosion, disturbed riparian habitat, and degraded in-stream habitat can result at point discharge locations (Booth et al., 2002).
- *Density and Market Implications*. Duration-control design standards in Washington Department of Ecology's (Ecology) 2005 *Stormwater Management Manual for Western Washington* will require larger ponds. As a larger percentage of land is designated for stormwater management within the development, stormwater infrastructure costs will increase and the number of buildable lots will likely decrease.

1.4 Low Impact Development

The conventional, purely structural approach to manage stormwater runoff has limitations for recovering adequate storage and spatially distributed flow paths necessary to more closely approximate pre-development hydrologic function and protect aquatic resources from adverse effects of development. Low impact development (LID) principles and applications present a significant conceptual shift from a purely structural approach. LID is primarily a source reduction approach. Site planning and stormwater management are integrated at the initial design phases of a project to maintain a more **hydrologically functional landscape**. Hydrology and natural site features that influence water movement guide road, structure, and other infrastructure layout. Native soil and vegetation protection areas and landscaping that are strategically distributed throughout the project to slow, store, and infiltrate storm flows are designed into the project as amenities, as well as hydrologic controls.

Pre-development or natural hydrologic function is the relationship among the overland and subsurface flow, infiltration, storage, and evapotranspiration characteristics of the forested landscape predominant in the Puget Sound lowland (see Section 1.1). Low impact development strategies focus on evaporating, transpiring, and infiltrating stormwater on-site through native soils, vegetation, and bioengineering applications to reduce and treat overland flow that is characteristically negligible in the forested setting.

Low Impact Development defined

Low impact development is a stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes conservation and use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions.

1.4.1 The Goal of Low Impact Development

The goal of LID is to prevent measurable harm to streams, lakes, wetlands, and other natural aquatic systems from commercial, residential, or industrial development sites. The impact to receiving waters (and determining if a project has achieved the above goal) is estimated by hydrologic models and measured by monitoring surface and ground water quality and quantity, and biological health.

1.4.2 Flow Control Objective

The primary stormwater management objective for LID is to match pre-development forested hydrologic condition (or prairie condition if historic records indicate that as the native setting) over the full range of rainfall intensities and durations.

1.4.3 Flow Control Objective Discussion

Maintaining the pre-development hydrologic regime cannot be achieved everywhere or at all times given current development practices. The hydrologic system of our region evolved from, and is dependent on, the characteristics of undisturbed Pacific Northwest watersheds—mature forest canopy, uncompacted soils, ungullied hillslopes—and cannot be expected to have the same hydrologic regime when significant portions of a site are disturbed. The objectives of any given low impact development, therefore, must be strategically chosen, recognizing both the opportunities and the limitations of any given site. Regulatory requirements, typical zoning and housing types, and costs of sophisticated control technology required on sites with poor soils and higher densities, as well as site topography, soil permeability and depth, and groundwater movement create significant challenges for reducing or eliminating hydrologic impacts from development sites. These challenges are likely to be most prominent during periods of extended rainfall, where the distributed on-site infiltration reservoirs common to most LID designs will experience their highest water levels and approach, or reach, full saturation.

Initial monitoring in the Puget Sound region suggests that LID strategies can be effective for maintaining pre-development hydrologic condition for light to moderate storm events typical of a maritime climate (Horner, Lim and Burges, 2002). Effectiveness in mimicking pre-development hydrology for large storms and during extended wet periods is not well documented. On difficult sites with low infiltration rates and higher densities, additional storage using conventional retention or detention pond facilities may be necessary in concert with LID strategies. Properly designed and implemented LID applications will, however, significantly reduce pond size requirements (Derry, Butchart and Graham, 2004 and Horner et al., 2002).

Properly designed and implemented LID applications will significantly reduce the size requirements of ponds.

1.4.3.1 Rural setting

Empirical data coupled with hydrologic modeling analysis, at the watershed scale, suggest that retaining 65 percent mature forest cover is necessary to mimic pre-development hydrologic conditions and maintain stable stream channels on moderately sloping till soils and typical rural development settings (EIA 3 to 5 percent). While this is an estimate of complex hydrologic processes, the 65 percent cover is a defensible target for forest protection in rural densities (see Figure 1.8) (Booth et al., 2002).

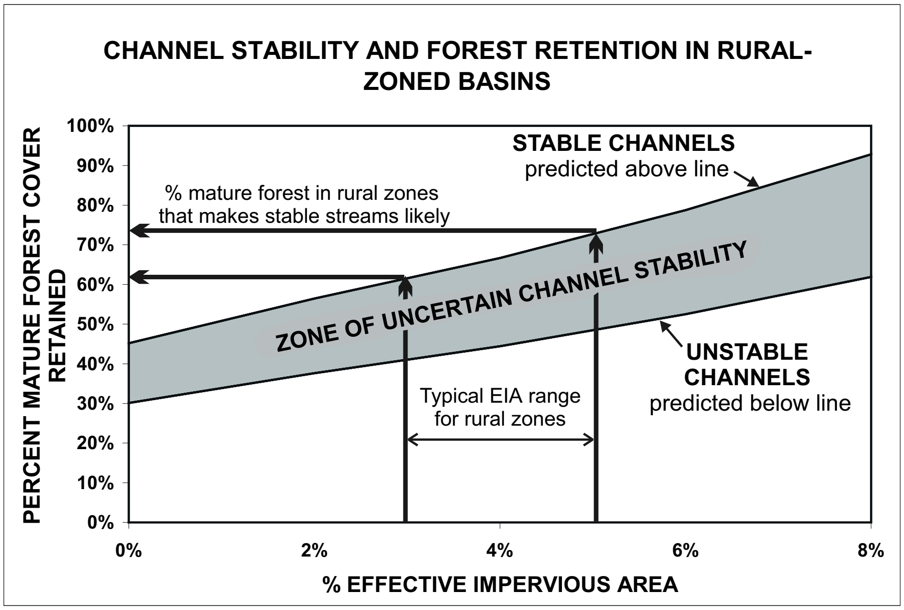

Figure 1.8 Modeled channel stablity plotted by percent forest cover retained and percent EIA (Booth et al., 2002).

Forested glacial outwash soils produce less overland flow than forested till soil conditions during storm events. As a result, forest clearing and increased impervious surface coverage can produce relatively larger peak-flows and increases in volume on outwash soils without adequate infiltration practices (Booth et al., 2002). The impact of concentrating infiltration facilities at a single location on outwash soils is not known; however, shallow subsurface flows may alter hydrologic characteristics if the development and facility are located proximate to a headwater stream.

Stormwater pollutant treatment is required when infiltrating stormwater on outwash soils from pollution generating surfaces (Washington Department of Ecology [Ecology], 2001). Processing pollutants in a facility that collects storm flows from an entire development can significantly increase infrastructure requirements and costs. Accordingly, 65 percent native soil and vegetation protection and *application of dispersed LID infiltration practices* is recommended for protecting stream and wetland habitat in the forested outwash soil and the rural setting.

1.4.3.2 Medium and high-density settings (6 or more dwelling units per acre)

The 65 percent target for mature native vegetation coverage may be achievable in medium and high-density settings by applying multifamily, cottage, or condominium type development. Sixty-five percent native vegetation and soil protection is not feasible with conventional single family detached housing at such densities. In the higher density setting, *comprehensive application of LID practices* is necessary to reduce the hydrologic changes and pollutant loads to surface and ground waters where less forest protection area is possible (see Chapter 3: Site Planning and Layout for design strategies).

Initial research modeling experimental, medium-density, residential LID designs indicates that pre-development hydrologic conditions may be approximated on soils with low infiltration rates when using the full suite of LID practices and 40 to 50 percent open space protection (CH2M HILL, 2001). In this difficult type of development scenario it is essential to apply a full complement of LID practices. Soil enhancement, bioretention, open conveyance, dispersion to open space, minimal excavation foundation systems, aggregate storage under paving, and roof water harvesting techniques must be integrated into the design to minimize hydrologic impacts. Eliminating the roof water contribution through roof water harvesting systems is essential for achieving the LID flow objective where higher density projects are located on soils with low infiltration rates.

1.4.4 Flow Control Objective and Department of Ecology's *Stormwater Management Manual for Western Washington*

This document or the flow control objective recommended in this manual does not supercede Ecology's 2005 *Stormwater Management Manual for Western Washington*. Where the Ecology manual is adopted, the minimum flow control standard for new development will be required to match 50 percent of the two-year event up to the full 50-year peak flows for a pre-developed forested condition (or prairie conditions if historic records indicate that as the native setting).

1.4.5 Site Design and Management Strategies to Meet Flow Control Objectives

The goal and flow control objective for LID are achieved through the following site design objectives. The objectives are grouped into four basic elements that constitute a complete LID design.

Conservation measures

- Maximize retention of native forest cover and restore disturbed vegetation to intercept, evaporate, and transpire precipitation.
- Preserve permeable, native soil and enhance disturbed soils to store and infiltrate storm flows.
- Retain and incorporate topographic site features that slow, store, and infiltrate stormwater.
- Retain and incorporate natural drainage features and patterns.

Site planning and minimization techniques

- Utilize a multidisciplinary approach that includes planners, engineers, landscape architects and architects at the initial phases of the project.
- Locate buildings and roads away from critical areas and soils that provide effective infiltration.
- Minimize total impervious surface area and eliminate effective impervious surfaces.

Distributed and integrated management practices

- Manage stormwater as close to its origin as possible by utilizing small scale, distributed hydrologic controls.
- Create a hydrologically rough landscape that slows storm flows and increases **time of concentration.**
- Increase reliability of the stormwater management system by providing multiple or redundant LID flow control practices.
- Integrate stormwater controls into the development design and utilize the controls as amenities—create a multifunctional landscape.
- Reduce the reliance on traditional conveyance and pond technologies.

Maintenance and Education

- Develop reliable and long-term maintenance programs with clear and enforceable guidelines.

- Educate LID project homeowners and landscape management personnel on the operation and maintenance of LID systems and promote community participation in the protection of those systems and receiving waters.

Subsequent sections of the manual—Chapter 3: Site Planning and Layout; Chapter 4: Vegetation Protection, Reforestation and Maintenance; Chapter 5: Site Clearing and Grading; Chapter 6: Integrated Management Practices; and Chapter 7: Flow Modeling Guidance—will provide information on low impact development tools and techniques that can be used to meet the objectives and strategies listed above. The manual outlines many of the tools available for designing a low impact development system, but it does not provide an exhaustive list of practices. The LID approach is creative and designers must consider the attributes of individual sites in the context of the local jurisdiction and community setting. Designers should apply sound science, an interdisciplinary approach and, at times, unique applications to meet LID goals and objectives. See Table 1.2 for a list of some LID techniques.

Table 1.2 LID techniques (checked items are examined in this manual).

X	Site assessment	X	Maintenance		Downspout dispersion
X	Site planning and design	X	Amending construction site soils	X	Roof stormwater harvesting systems
X	Site phasing and fingerprinting	X	Permeable asphalt		Filter strips
X	Preserving native soils and vegetation	X	Permeable concrete		Media filtration
X	Clearing and grading	X	Permeable gravel pave systems		
X	Bioretention cells	X	Permeable pavers		
X	Sloped biodetention	X	Vegetated roofs		
X	Bioretention swales	X	Minimal excavation foundations		
	Tree box filters		Homeowner education		

While the focus of low impact development and this manual is to more effectively manage stormwater, LID can and should address other livability issues including:

- Residential road design that reduces traffic speeds and promotes walking and biking as alternative transportation methods.
- Development at appropriate densities that meets Growth Management Act goals, and increases access to, and connection between, public transportation modes.
- Subdivision layout and building design that promote interaction between neighbors and the connection to open space and recreation areas.

1.4.6 Low Impact Development in the Watershed Context

LID is a tool for retrofitting existing or constructing new commercial and residential development at the parcel and subdivision scale. Maintaining aquatic habitat, water quality, species of special concern, and healthy aquatic systems in general requires protection or restoration of processes (for example the movement of water and recruitment of large woody debris) and structures (forest canopy, soils, etc.) at the sub-watershed, watershed or regional scale.

To protect high quality, sensitive stream systems the following critical area designations and associated land use controls are necessary:

- Extensive and near continuous riparian buffer protection.
- Floodplain protection.
- Aggressive native forest and soil protection.
- Limit EIA to approximately 10 percent.

(Horner, May, Livingston, Blaha, Scoggins, Tims, Maxted, 2001 and May et al., 1997)

Where higher levels of EIA and development exist or are proposed and ecological function is good or impaired (but not entirely lost), several strategies can be employed for protection and enhancement including, but not limited to: forest and soil restoration; comprehensive drainage design addressing cumulative impacts and implementing regional stormwater control facilities; and other mitigation and enhancement measures (May et al., 1997).

To improve sub-watershed or regional scale ecosystem functions, basin assessments must evaluate the quality and sensitivity of resources, and the cumulative impacts of existing development, future growth and other activities in sub-watersheds. Through the assessment and planning process, managers should set priorities for resource protection for sub-watersheds based on resource sensitivity and growth pressures. Various landscape analysis tools are available that allow managers to assign appropriate densities and types of development based on the projected cumulative impacts of different land use scenarios.

1.4.7 Low Impact Development and Comprehensive Stormwater Management

LID does not compensate for the cumulative and adverse effects from road networks and other land clearing activities that occur outside the development site. Low impact development can, however, be used in the various sub-basin development scenarios to help achieve larger-scale, sub-watershed protection goals. Implemented comprehensively, native soil and vegetation protection, soil improvement, and increased on-site storage and infiltration capacity at the site level are necessary to protect or enhance larger-scale hydrologic function and other watershed attributes.

While LID works with and supports the effective implementation of regional stormwater management plans and land use planning under the Growth Management Act, it is not a substitute for these local government responsibilities. The use of LID techniques should be part of a local, comprehensive stormwater management program that includes:

- Adoption and use of Ecology's 2005 *Stormwater Management Manual for Western Washington* (or an alternative manual that is technically equivalent).
- Regular inspections of construction sites.
- Maintenance of temporary and permanent facilities.
- Source control.
- Elimination of illicit discharges.
- Identification and ranking of existing stormwater problems.
- Public education and involvement.
- Watershed or basin planning.
- Stable funding.
- Programmatic and environmental monitoring.

(Puget Sound Action Team, 2000)